Electrostatic Charging of Polymers by Particle Impact at Martian Atmospheric Pressures

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Abstract: Studies of the electrostatic interaction between micrometer-sized particles and polymer surfaces are of great interest to NASA's planetary exploration program. The unmanned landing missions to Mars planned for this decade as well as the possible manned missions that might take place during the second decade of this century require a better understanding of the electrostatic response of the materials used in landing crafts and equipment when exposed to wind-blown dust or to surface dust and sand particles. We report on preliminary experiments designed to measure the electrostatic charge developed on three polymer surfaces as they are impacted by Mars simulant particles less than 5 micrometers in diameter moving at 20 m/s. Experiments were performed in a CO_2 atmosphere at 10 mbars of pressure using a particle delivery method that propels the particles without contact. The polymer surfaces, commonly used in space applications, were chosen so that they span the triboelectric series.

Introduction

Meteorological sensors on the Viking Landers and on Pathfinder as well as the extensive measurements by several Mars Global Surveyor instruments have provided a great deal of accurate data on the Martian atmosphere. Pathfinder found patterns of diurnal and longer-term pressure and temperature fluctuations. The temperature ranged from a minimum of 197 K (–76 degrees Celsius), reached just before sunrise, to a maximum of 263 K (–10 degrees Celsius), reached every day at 2 p.m. local solar time. The pressure minimum was measured to be just under 6.7 millibars (reached on the 20th Martian day after landing), while the pressure maximum was measured at 6.86 mbars. Measurements made over a three and a half year period by the Viking Landers showed that the pressure reached minimum values of about 6.7 mbars and maximum values of about 10.4 mbars.

Calculations have shown that the average dust particle in the Martian atmosphre has a diameter of about 1 μm. The mechanism that airlifts dust in the tenous Martian atmosphere is not known in detail. Small, localized duststorms, known as dust devils, observed by Pathfinder with daily frequency, are thought to be a possible mechanism for airlifting dust into the atmosphere. Local duststorms that last approximately one day have been observed. A few times each Martian year, a local duststorm grows into one that engulfs the entire planet [*Martin*, 1974]. These global dust storms may last for several months.

Stationary surface soil and dust particles on Mars may be electrostatically charged due to incident UV radiation reaching the surface. Although the total integrated UV flux over 200-400 nm is comparable to Earth's, shorter wavelengths contribute a larger proportion of this flux [*Catling* and *Cockell*, 2000]. Contact charging may also occur due to collisions between wind-blown dust particles and stationary surface particulate matter. The high frequency of dust devil appearance and the presence of local and global dust storms produce a favorable environment for inter-particle contact charging in the Martian atmosphere.

The unmanned landing missions to Mars planned for this decade as well as the possible manned missions that might take place during the second decade of this century require a better understanding of the electrostatic response of the materials used in landing crafts and equipment when exposed to wind-blown dust or to surface dust and sand particles. No experiments to determine the magnitude of the charge exchange between contacting particles or between airborne moving particles and stationary surfaces has been conducted in any Mars exploration mission so far. In this paper, we report on experiments performed in our laboratory with Martian soil simulant impacting on several polymers. We present data on the electrostatic charge exchange produced by these interactions.

Martian Environmental Simulation

A Martian regolith soil simulant prepared by scientists at NASA Johnson Space Center from Hawaiian volcanic ash to simulate the Martian soil [*Allen et al*, 1998] was used in our experiments. This simulant approximates Viking and Pathfinder measurements of reflectance spectrum, mineralogy, chemical composition, ground grain size, density, porosity, and magnetic properties. Table 1 shows the mineral composition of this simulant as compared with the mineral composition of the Martian soil measured by Viking and Pathfinder. As this table shows, SiO_2, Fe_2O_3, Al_2O_3, SO_3, MgO, and CaO are the major components of the Martian soil.

Table 1. JSC Mars-1 Chemical Composition (Wt%)

Oxide	**Viking 1**	**Pathfinder**	**JSC Mars-1**	
			Fine	**Coarse**
SiO_2	43	44.0	40.2	39.3
Al_2O_3	7.3	7.5	25.1	26.2
TiO_2	0.66	1.1	3.53	3.42
Fe_2O_3	18.5	16.5	12.4	15.6
MnO	NA	NA	0.65	0.49
CaO	5.9	5.6	4.08	3.51
MgO	6	7.0	1.14	0.97
K_2O	<0.15	0.3	NA	NA
Na_2O	NA	2.1	1.79	0.91
P_2O_5	NA	NA	1.13	1.91
SO_3	6.6	4.9	0.86	0.29
Cl	0.7	0.5	NA	NA
LOI*	NA	NA	21.8 [ϒ]	

*LOI: Loss on ignition. Weight loss after 2 hrs at 900°C; includes H_2O and SO_2

ϒ[*Allen et al* 1998]

To simulate the Martian atmospheric environment, our laboratory has designed two dedicated thermal vacuum chambers. Operation of these chambers is automated with a LabView graphical interface that control banks of programmable logic controllers [*Calle et al* 2001a; *Calle et al* 2001b, *Buchanan et al* 2001]. Cooling plates provide temperatures ranging from 180 K to 473 K. Atmospheric pressures range from 0.3 mbars to 1013 mbars. Since the Martian atmosphere is 95% carbon dioxide, the chambers are normally evacuated to 0.3 mbars and backfilled to the operating pressure (usually 9 mbar) with a 100% CO_2 atmosphere.

Figure 1. The Mars environmental chambers at NASA Kennedy Space Center's Electromagnetic Physics Laboratory.

Simulation of a windstorm requires the ability to airlift micrometer-sized particles at the low pressures of the Martian atmosphere. Extremely high wind speeds are needed to airlift particles of less than 10 μm in diameter [*Greeley* 1994]. We have developed a Dust Impeller, a device to propel submillimeter-size particles without contact at speeds up to 20 m/s at low pressures (Figure 2) [*Calle et al* 2001c, *Calle et al* 2002]. This device essentially creates a windstorm in a vacuum chamber. Constant wind speeds of 20 m/s have been measured with the dust impeller operating at gas pressures ranging from 5 mbar to 1 bar.

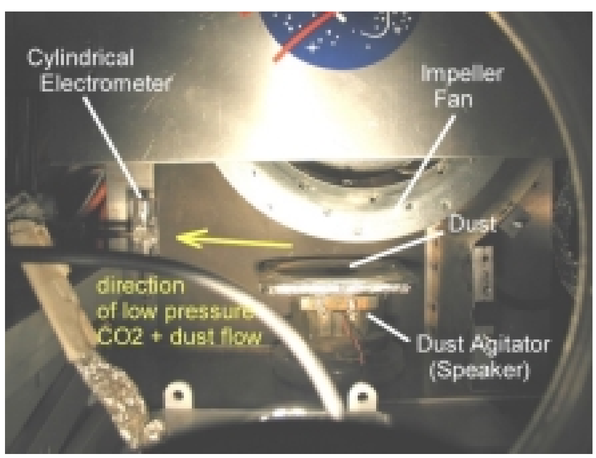

Figure 1. The KSC dust particle impeller operates at low pressures and is capable of propelling dust particles at atmospheric pressures and pressures as low as 5 mbar.

Multisensor Electrometer

An aerodynamic electrometer to measure the electrostatic and triboelectric properties of simulated Martian atmospheric dust has been developed (Fig. 3) [*Calle et al* 2002]. This instrument consists of an array of insulating materials with each material backed by a miniature electrometer. The electrometer sensor uses a simple reference capacitor design as was used on the Mars Environmental Compatibility Assessment (MECA) Electrometer [*Buehler et al* 2000, *Mantovani et al*], a flight-ready instrument that included five sensors in a line array. The probe of the new instrument consists of a field-sensor electrode that is enclosed by a guard electrode, which in turn is enclosed by an electrically grounded shield. The probe is embedded in a cylinder to within 2.5 mm of the surface. The overall gain of the electronic circuit is 0.25 pC/mV. The current version of the instrument contains six sensors to measure the electric field induced by any net charge on six different insulator surfaces. The charge develops through frictional contact between the cylindrically shaped insulators and incident granular material.

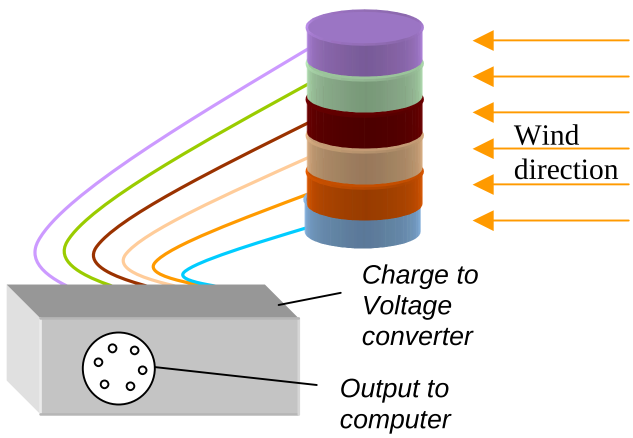

Figure 3. Diagram of the aerodynamic electrometer and its associated electronic housing is shown with sensor/guard probes embedded in six cylindrical insulators.

Experiments

JSC Mars-1 simulant, already in granular form, was used in these experiments. Particles of SiO_2, Fe_2O_3, Al_2O_3, and CaO, four of the simulant's six major components, were also used. These particles, ranging in diameters from 5 to 17 μm, were baked at 150 °C for at least 24 hours to remove moisture before being placed in the dust particle impeller inside the thermal vacuum chamber containing a room temperature CO_2 atmosphere at 9 mbar. The chamber was slowly evacuated to 0.3 mbars, subsequently backfilled twice with CO_2 to 133 mbar, and then pumped back down to 9 mbar before data were taken.

After the impeller was turned on, about 1 gram of granular material was propelled towards the cylindrical polymers of the electrometer (Fig. 3). Initial experiments were performed using individual polymer cylinders (Fig. 4). Teflon, Fiberglass, and Lucite cylinders were used in these experiments. Wind speeds of 20 m/s were generated with the dust particle impeller at 9 mbar. Actual particle speeds were not measured in these initial experiments. Particle impact on the polymer cylinder was uneven due to aerodynamics considerations. Fig. 4 shows a Teflon cylinder coated with fine (≤ 5μm in diameter) JSC Mars-1 simulant dust particles. The output voltage of the electrometer sensor is a measure of the local electric field that is induced on the electrometer's probe sensor electrode. The amount of charge that develops on the insulator surface can be determined from the output voltage using the circuit gain of 0.25 pC/mV.

Figure 3. Dust particles being impelled towards the cylindrical electrometer. Photo taken through a viewport of a vacuum chamber being operated at 10 mb in CO_2 atmosphere.

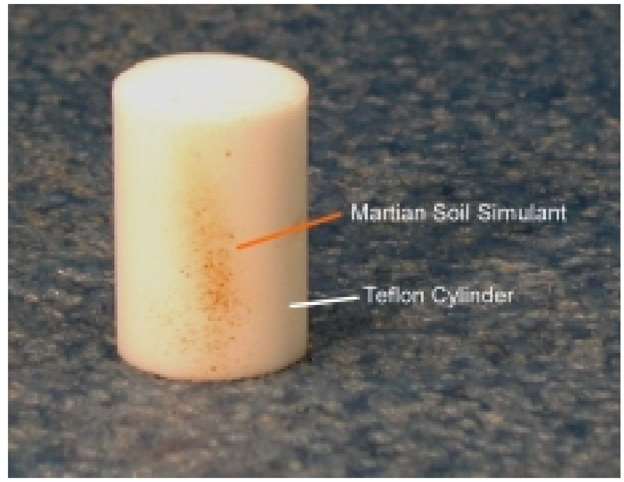

Figure 4. Teflon cylinder used in initial experiments with a single electrometer probe shows JSC Mars-1 simulant dust particles adhering to it after one run at 9 mbars.

Results and Discussion

We present data showing the electrostatic charge generated on Teflon, Fiberglass, and Lucite cylinders as they were impacted by five different granular materials. The cylinders (which ranged in diameter from 1.9 cm for Teflon to 2.5 cm for Fiberglass and Lucite) were exposed to windborne dust particles in separate experiments. Data were taken in a vacuum chamber containing a room temperature CO_2 atmosphere at 9 mbar. Fig 5 shows data for Teflon and Fiberglass cylinders that were struck in separate experiments by JSC Mars-1 simulant particles. Figures 6 through 9 show data for Teflon, Fiberglass, and Lucite cylinders exposed to SiO_2, Fe_2O_3, Al_2O_3, and CaO particles respectively. The output voltage of the electrometer is a measure of the local electric field that is induced on the electrometer's probe sensor electrode. The amount of charge that develops on the insulator surface can be determined from the output voltage using the circuit gain 0.25 pC/mV. We have overlaid Teflon and Fiberglass data in Figure 5 and Teflon, Lucite, and Fiberglass in Figs. 6-9. With regard to the amount of charge that develops on the polymer surfaces, only voltage differences have meaning.

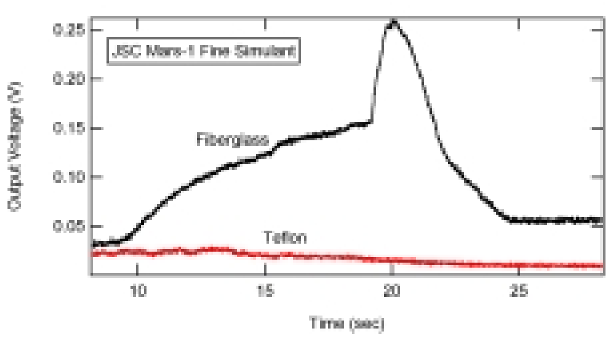

Figure 5. Electrometer responses to JSC Mars-1 Simulant particles striking Fiberglass and Teflon cylinders.

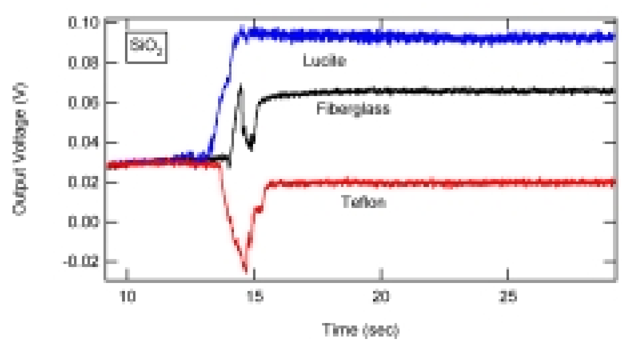

Figure 6. Electrometer responses to SiO_2 particles striking Fiberglass, Lucite and Teflon cylinders.

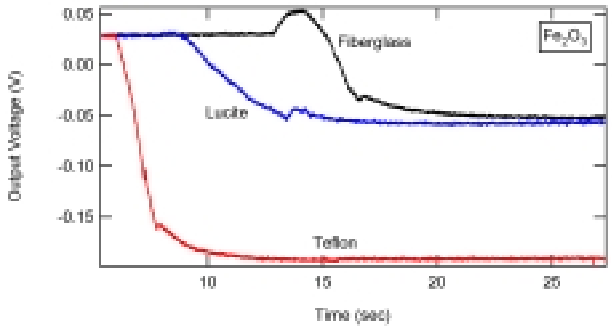

Figure 7. Electrometer responses to Fe_2O_3 particles striking Fiberglass, Lucite and Teflon cylinders.

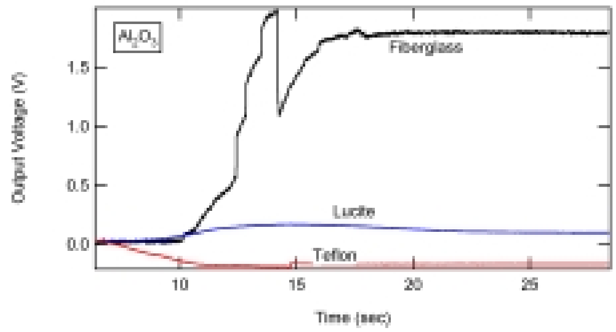

Figure 8. Electrometer responses to Al_2O_3 particles striking Fiberglass, Lucite and Teflon cylinders.

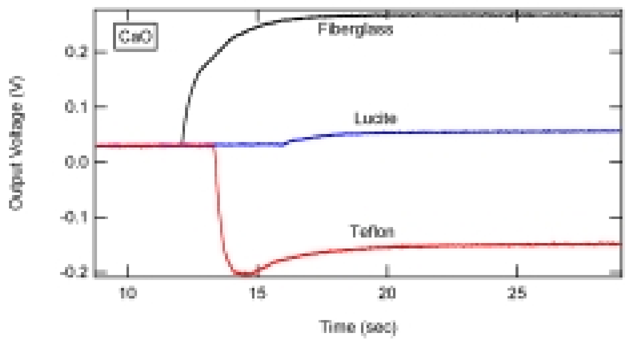

Figure 9. Electrometer responses to CaO particles striking Fiberglass, Lucite and Teflon cylinders.

We note that the actual voltage levels attained during each run depend upon conditions that are difficult to control, such as the flow pattern of windborne dust particles, and the charging of dust particles due to particle-particle collisions. The JSC Mars-1 simulant is a complex mixture of several minerals. The electrostatic interaction with other materials, as shown in Fig. 5, depends not only on particle size, particle speed, and environmental conditions, but also on the nature of its components. The electrostatic behavior of its major components may yield clues about the overall behavior of the simulant itself. The results summarized in Figs. 6 though 9 are a first attempt at this characterization. Since these results were obtained with an earlier prototype, which did not allow for simultaneous exposure of the polymers to the granular material, the conditions may not be exactly the same for the three polymers. An overall trend is observed, however. Table 2 lists the ordering of the minerals and the polymers in a triboelectric series, based on the data shown in Figs. 6-9.

Table 2. Triboelectric Series

Polymer	Mineral
Most Positive	
	Fe_2O_3
Fiberglass	
Lucite	
	CaO
	Al_2O_3
	SiO_2
	JSC Mars-1
Teflon	
Most Negative	

Future experiments with the multisensor electrometer shown in Fig. 3 are planned. In these experiments, granular materials will simultaneously strike the six polymers surfaces on the instrument. The average electrostatic responses of the polymers to the granular minerals may allow us to observe consistent differences in behavior, which could lead to a possible identification of such minerals.

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